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NRL Report 4820
Copy No. 40

THE TRANSMISSION OF PULSED LIGHT SIGNALS FROM LAND TO AIRCRAFT

[redacted]

G. L. Stamm, W. S. Plymale, Jr.,
and C. M. Whitfield, Jr.

Photometry Branch
Optics Division

September 11, 1956

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Subj: NRL [redacted]eport 4820, "The Transmission of Pulsed Light Signals from Land to Aircraft", ([redacted] by G.L. Stamm, W.S. Plymale, Jr., and C.M. Whitfield, Jr. dtd 11 September 1956; downgrading of

Ref: (a) Classification Change Notice 3-63
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ABSTRACT
[Secret]

Equipment for the generation and detection of high intensity light pulses has been developed. Composed of a transmitter and a receiver, the equipment was designed specifically for submarine-to-air signalling purposes. The transmitter and its operation are described in detail. Special attention is given to the light source, a flashtube which emits a light pulse having an effective duration of 0.65 microsecond and a total peak radiant intensity of about 120,000 watts between 300 and 680 millimicrons.

Some experimental data on the detectable horizontal ranges attained during land-to-air signalling are presented along with some visual observations made on the light pulse from the transmitter. Although the angular width of the light pulse beam is only thirteen to twenty-three degrees, signals from the transmitter were detected over a horizontal range of almost four miles at an altitude of 5000 feet. Also the effect on the equipment of maintaining visual security is discussed.

PROBLEM STATUS

This is an interim report; work is continuing on the problem.

AUTHORIZATION

NRL Problem N03-02
Project Nos. NE 120-713-2 and NR 673-020
BuShips Problem S-1625

Manuscript submitted August 3, 1956

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THE TRANSMISSION OF PULSED LIGHT SIGNALS FROM LAND TO AIRCRAFT

[Secret Title]

INTRODUCTION

Modifications have been made to old equipment and new equipment has been developed for the generation and detection of high intensity light pulses for signalling between submarines and aircraft. This work is an outgrowth of previous investigations undertaken and reported on in connection with the development of an optical identification or communication system between aircraft and submarines. Already examined have been the transmission of light in coastal (1) and ocean (2, 3) waters and the transmission of pulsed light from submarines to surface ships (4). Furthermore, the feasibility of a pulsed light IFF system between submarines and aircraft has been studied theoretically (3). These reports show that it is expedient at this time to gather experimental data on the detection of pulsed light signals transmitted from a submerged submarine to an aircraft. With this end in mind the present equipment has been designed and built, and some preliminary results have been obtained concerning its operation in the field.

The optical system consists essentially of two separate and distinct pieces of equipment; the transmitter and the receiver. A transmitter has been built specifically to satisfy the conditions imposed by submarine-to-aircraft signalling. The flashing rate has been increased greatly, and the duration of the light pulse has been decreased with only a correspondingly small reduction in the peak light intensity. Also, the transmitter has been made more compact and lighter in weight.

A receiver has been developed by means of which data can be gathered on the detectable horizontal ranges across the light pulse beam from the transmitter below. The light pulses are converted into audible notes which can be listened to by an operator in the aircraft. This type of receiver equipment finds usefulness especially on conventional aircraft whose speeds are such that there is little time for taking data in other ways.

The field testing of this equipment consisted of nine night runs over the transmitter which was stationed on land. The receiver, mounted in an airplane, was flown at several altitudes up to a maximum of 10,000 feet. Also, filters were placed over the transmitter to exclude certain visible portions of the spectrum. Although the angular width of the beam of light was very narrow, almost a four-mile horizontal range across the beam at 5000 feet was recorded.

LIGHT PULSE TRANSMITTER

The light pulse transmitter has been substantially changed from previous transmitters (2, 3). Transmitter TS-1A, containing all the components (on the left side of Fig. 1), fits into a tank (on the right side) to make a watertight unit which can be submerged. The size of the entire transmitter has been reduced at least one-third from the one described in a previous report (3). The tank is a steel cylinder a little over a foot in diameter and about one and one-half feet high. A corresponding weight reduction has been effected so that now the entire tank and components of the transmitter weigh 125 pounds. These decreases in

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size and weight are important from the standpoint that the transmitter is now easier [redacted] handle and to mount for possible attachment to the conning tower of a submarine so that it will be nearer the surface of the water.

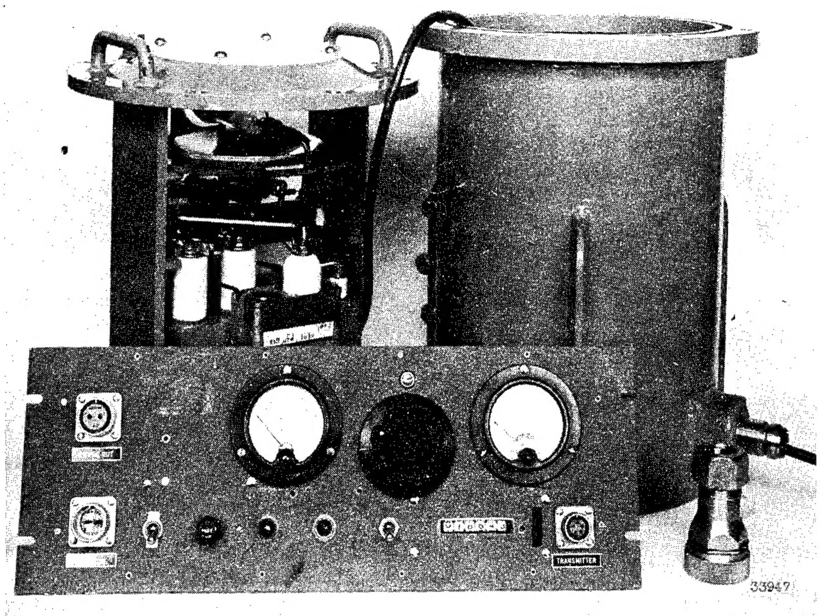


Fig. 1 - Transmitter TS-1A and Transmitter Controls TCS-1A

A sturdier cable is being used for electrical connections between the transmitter outside the submarine and the transmitter control panel within the submarine. A water-tight connector, shown to the right of the transmitter control panel in Fig. 1, is being employed to attach the cable directly to the transmitter tank after it has been put into place aboard the submarine, thus decreasing the possibility of fracturing the power cable. Also, the heavier cable will withstand the high underwater pressures and drag very satisfactorily.

The changes in the electronic circuitry within the transmitter have been extensive (Fig. 2). The flashing rate has been increased by a factory of twenty-five and now has a maximum rate of five flashes per second. Since the value of the charging resistor is critical at such high flashing rates, consideration had to be given to the amount of average power which the power supply can deliver, the peak current which can be drawn, and the power which is dissipated in the discharge circuit containing the flashtube and in the charging resistor. For a given power supply and energy storage capacitor there is an optimum value of charging resistance which will allow the maximum flashing rate to be attained without overloading the components. The power supply was chosen for its compact design and its ability to deliver sufficient power to permit a suitable flashing rate. Smaller components have been used throughout, and space has been used more judiciously.

One of the difficulties which had to be overcome was the extinction of the direct-current arc which is set up in the LSD-2 flashtube when the voltage across it changes very

rapidly. Due to the fast flashing rates required in the present experiments in the field, the voltage across the energy storage capacitor and the LSD-2 flashtube necessarily had to rise rapidly. Thus, upon charging the energy storage capacitor the direct-current arc appeared and prevented the voltage from rising at the anode of the flashtube for the next discharge. This problem has been recognized before (5). However, suggested solutions involved either methods which would call for considerable reduction of energy input to the flashtube or the incorporation of space-consuming components in the discharge circuit.

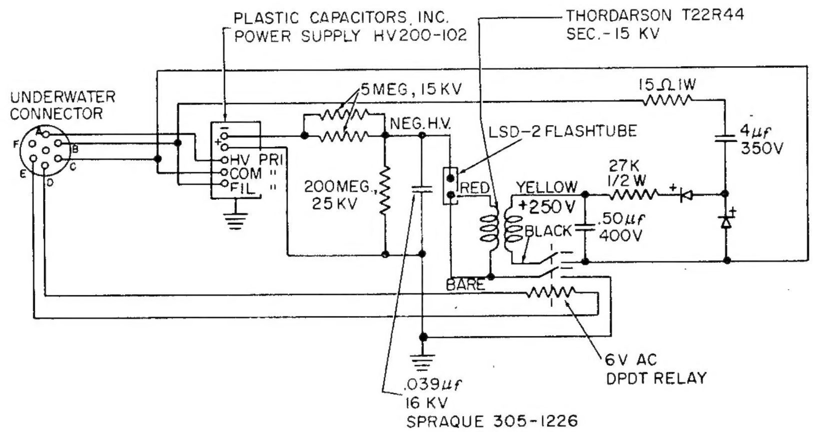


Fig. 2 - Circuit diagram for Transmitter TS-1

A relatively simple way to extinguish the direct-current arc was finally discovered. Its operation can be understood by referring to Fig. 2. One side of a double pole, double throw relay, which is connected in series into the ground side of the discharge circuit, opens after each discharge in order to prevent the steady arc from forming during the charging period. After the energy storage capacitor is fully charged, the relay closes, thus simultaneously triggering the flashtube and connecting the cathode to ground to complete the discharge path. It immediately opens again in readiness for the next cycle. Some sparking is encountered at the relay contacts so a relay having special contact material is required.

The transmitter controls have also been changed considerably in several ways (Fig. 3). The operation of the transmitter can be remotely controlled either automatically or manually. If automatic operation is desired, the transmitter will send out pulses up to a maximum of five per second. This rate can be decreased so that a code can be transmitted if desired. Also, a key can be used to initiate light pulses if manual operation is desired. Here again the pulse rate must be limited to a maximum of five per second.

A counter has been installed in the transmitter control panel for acquiring data on the life of flashtubes. It is a continuously recording counter and maintains a record of the total number of times the flashtube is triggered.

The light pulse is emitted from a LSD-2 flashtube by discharging an energy storage capacitor through it. The energy dissipated in the discharge circuit is given by the relation

$$E = 0.5\ CV^2$$

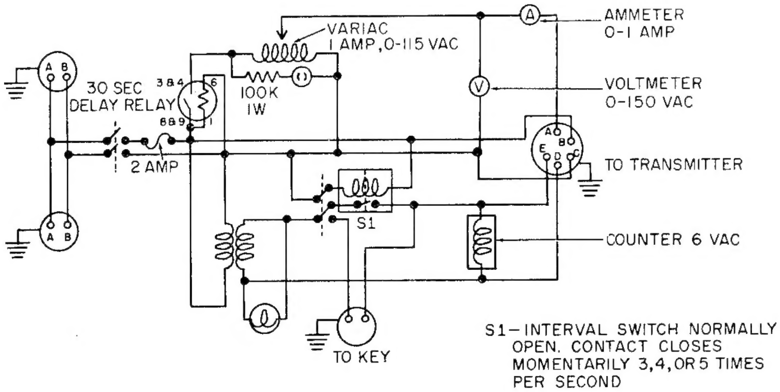


Fig. 3 - Circuit diagram for Transmitter Controls TCS-1

where

E = energy dissipated

C = capacitance of the energy storage capacitor

V = voltage to which capacitor is charged.

In the present equipment a 0.039-μf capacitor is charged to a potential of approximately 9 kv, thus releasing 1.58 watt-seconds of energy each time a light pulse is emitted. The average power consumption at the maximum flashing rate of five flashes per second is 7.90 watts. The high voltage placed across the flashtube is limited by the breakdown potential which varies considerably from one LSD-2 to another. On the average though, it is above 10 kv. The limits on the energy dissipated in each discharge are governed by the amount of power which the power supply can deliver at a given flashing rate and by the life expected of the flashtube. The flashtube will have a shorter life at higher discharge energies than at lower ones.

The light pulse emitted from the transmitter has been shortened substantially. In Fig. 4 the horizontal time scale is 0.20 microsecond per division. The rise time of the light pulse is 0.20 microsecond, and the pulse is only 0.65 microsecond wide at the half-intensity points. By introducing an energy storage capacitor of a lower capacitance into the discharge circuit and raising the operating voltage of the flashtube, a shorter light pulse has been produced. It has been found that of those energy storage capacitors designed to have minimum internal inductance and resistance, the lower capacity ones exceed in these two characteristics. Thus, shorter duration light pulses are realized when capacitors of lower capacitance are used to discharge energy into the flashtube.

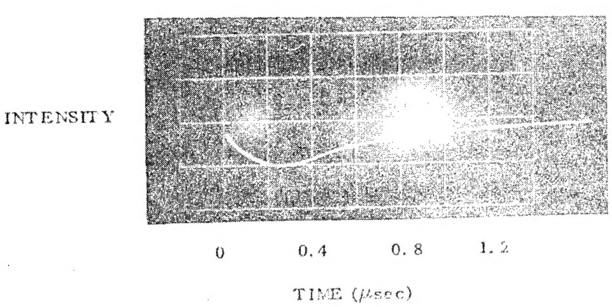


Fig. 4 - Time-intensity characteristics of light pulse from Transmitter TS-1A

The light output from the new transmitter has been reduced slightly. This has resulted from limitations imposed due to weight and size reductions which have been effected and especially by the fact that the flashing rate has been increased by a factor of 25. Nevertheless, the total peak spectral radiant intensity of the light from the LSD-2 in the transmitter in the region 300 to 680 millimicrons is still high at about 120,000 watts. The relative spectral distribution of the radiant energy is approximately the same as previously reported (3).

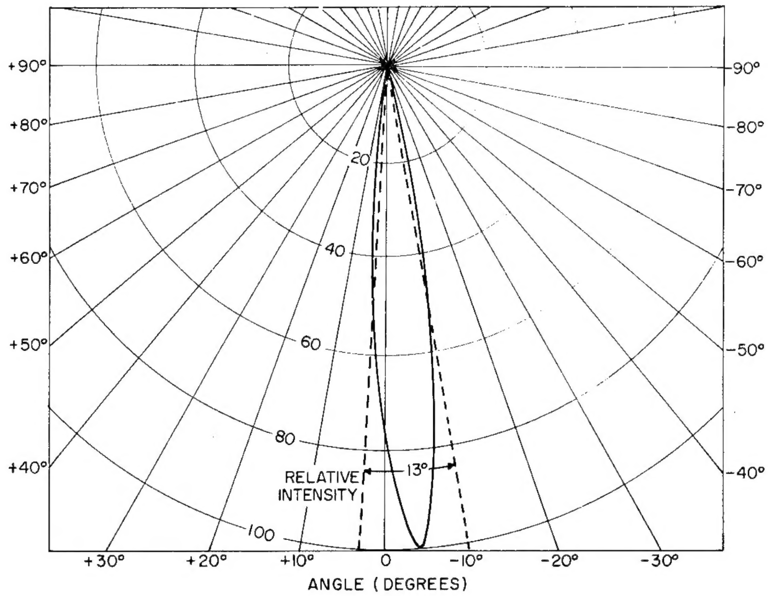
The beam of light emitted from the transmitter is by no means isotropic and sharply defined. This is so for two reasons: (1) the light source is an intensely brilliant column only about one-half millimeter wide but thirty millimeters long, and (2) the mirror reflecting the light out of the transmitter contains several distortions. Furthermore, the beam of light jumps around slightly from one light pulse to another due to the fact that the discharge column does not follow a straight path each time from the cathode to the anode. Instead, it is crooked and bowed with a maximum variation of 25 millimeters occurring in the position of the discharge column from one light pulse to another.

Figure 5, which presents two views of the average relative angular peak radiant intensity of the light pulse from Transmitter TS-1A, should be considered from the standpoint of the variations which have been mentioned. All measurements were made at a distance of 1040 feet from the transmitter, and the relative peak intensities given are the result of averaging over many light pulses. In order to obtain these data, the transmitter was placed on its side and pointed directly at the distant detector such that they were both in the same horizontal plane. Then, the transmitter was rotated about a vertical axis running through the flashtube, and readings were taken at various angles to determine the intensity distribution of the light pulse beam as shown in Fig. 5. Each beam shown has a different angular distribution according to the orientation of the flashtube in the transmitter with respect to the horizontal plane of measurements, which includes the transmitter and the detector. The measurements for Fig. 5a were taken with the axis of the flashtube vertical and thus perpendicular to the plane of measurements, whereas Fig. 5b presents data taken with the axis of the flashtube horizontal and contained in the plane of measurements.

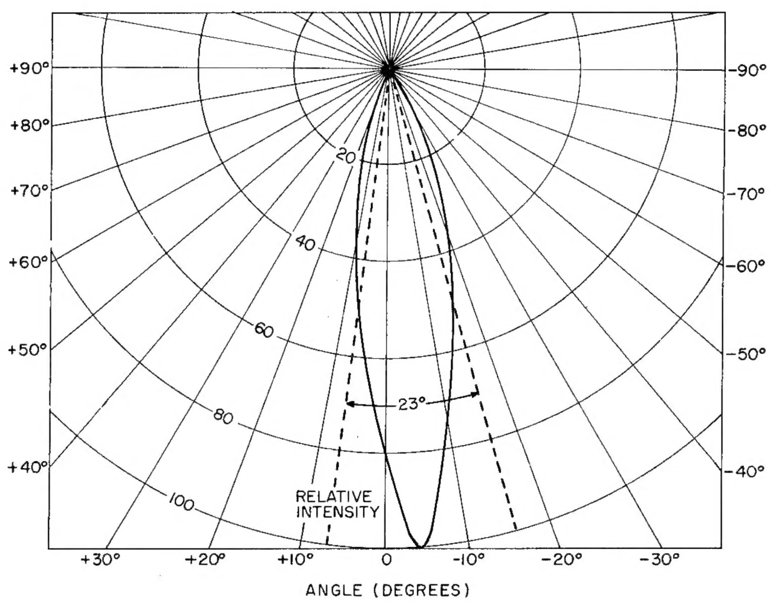
In Fig. 5, the dotted lines are drawn from the transmitter through the points on the envelope at which the peak intensity has diminished to one half its maximum value. At angles greater than those included by the dotted lines the peak intensity falls off to very low values, and at angles included by the dotted lines the peak intensity is equal to or more than one half its maximum value. The angle included by the dotted lines is here defined as the light pulse beam. The plane in which the light pulse beam opens up into its narrowest angle is shown in Fig. 5a to be 13 degrees, while the plane in which the beam is widest is shown in Fig. 5b to be 23 degrees. The wider angle produced in Fig. 5b is due to the long path length of the discharge column in the flashtube.

LIGHT PULSE RECEIVER

The light pulse receiver was built especially for installation aboard an aircraft which would pass over pulsed light signals at speeds of approximately 200 knots. The details of the receiver are reported elsewhere (6). It will suffice to say here that several variations of the receiver have been designed, all using the same basic principle of operation. The light pulse received at the detector is converted into an audible note which the operator listens to. This method circumvents the difficulties inherent in a system which visually displays the light pulse for measurement. The difficulties mentioned arise from two sources: (1) the speed of the aircraft and (2) the great spacial variation of the peak light intensity across the light pulse beam.



(a) - Axis of flashtube is vertical and perpendicular to the plane of measurements



(b) - Axis of flashtube is horizontal and contained in the plane of measurements

Fig. 5 - Average relative angular peak radiant intensity of light pulse beam from Transmitter TS-1A at 1040 feet

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The operation of the receiver in the field has been simplified considerably. It consists of turning up the sweep, trigger, and dynode voltage consecutively to a point which is just below that where spurious triggers are heard on the earphones. During flights over the transmitter, audible notes are heard on the earphones as soon as the aircraft approaches the light pulse beam sufficiently close that the signal strength is greater than the background noise. These audible notes will continue all the way across the light pulse beam until the opposite periphery has been reached. From the time recorded during which the notes are heard and the speed of the aircraft, the horizontal range over which the light pulses are detectable can be calculated.

The field of view of the detector is quite wide. During the preliminary flights to be described, a bare 6199 multiplier phototube was directed vertically downward from the aircraft. No optical system was employed in front of the phototube.

LAND-TO-AIRCRAFT SIGNALLING

Test flights were conducted over the transmitter on the night of 25 January 1956 between 2130 and 2230. There were chiefly four reasons for making these flights. They are: (1) to find out what kind of horizontal ranges to expect under the conditions of land-to-aircraft signalling with the present equipment, (2) to check the performance of the transmitter in the field, (3) to determine the operating characteristics of the receiver in an aircraft, and (4) to familiarize personnel with the operation of the equipment in the field.

The tests were conducted under conditions which were favorable to the transmitter but not especially favorable to the receiver. There was a fullmoon. The sky was clear and cloudless. The transmitter was stationed on open ground on the west side of Tilghman Island in the Chesapeake Bay, and runs were made by approaching it from a westerly direction. Thus, during the first part of each run, the detector was over the bay where reflected moonlight was clearly visible. During the latter part of each run, some land was directly below, but since it was in the country, there was very little visible radiation emanating from it.

A total of nine runs were conducted over the transmitter at several altitudes. Three runs were made over the bare transmitter at 1000 feet. At 5000 feet three more runs were made with a thin ultraviolet filter, UV-1A, inserted over the transmitter. The last set of three runs was made at 10,000 feet with a thick ultraviolet filter, UV-2A, in place over the transmitter. Figure 6 shows the spectral transmittances of these two filters. Filter UV-1A transmits some radiation in the near infrared, but the detector is insensitive in this spectral region.

Figure 7 shows the horizontal ranges obtained during the flight described above. The numbers indicate the particular run made across the light pulse beam. The plotted points lie at the periphery beyond which no signal is detectable. The angles formed by lines A and A′ and lines B and B′ represent the light pulse beam as plotted in Figs. 5a and 5b, respectively. It can be seen that the signal can be detected considerably outside the light pulse beam where the peak intensities are at quite low values compared with those inside the beam. The number of runs are insufficient and other factors, such as the aircraft's position with respect to the transmitter, make it impractical to correlate the horizontal range over which the signal is detectable with the angular width of the light pulse beam. It is surmised that the receiver was saturating greatly when it was within the light pulse beam. By averaging the peripheral distances at each of the three altitudes, the horizontal ranges over which a signal from the transmitter is detectable with a given filter in place

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can be calculated (Table 1). An indication of the horizontal ranges which can be attained by flying at higher altitudes may be obtained by extending each line in Fig. 7. However, the extensions will not necessarily be straight lines; they will be governed by the distance from the transmitter and the transmission of the atmosphere.

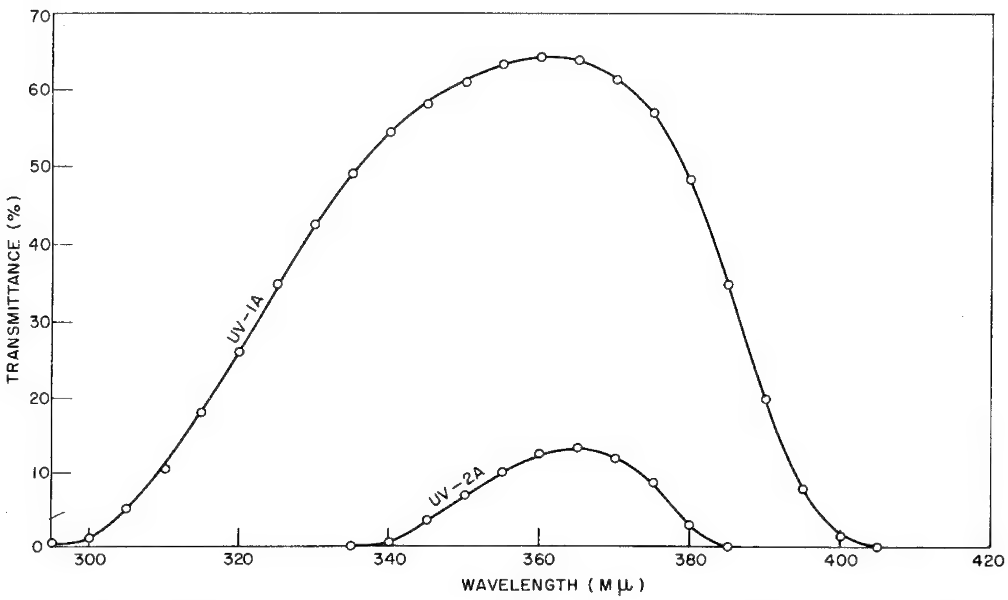

Fig. 6 - Spectral transmittances of filters UV-1A and UV-2A in the near ultraviolet region of the spectrum

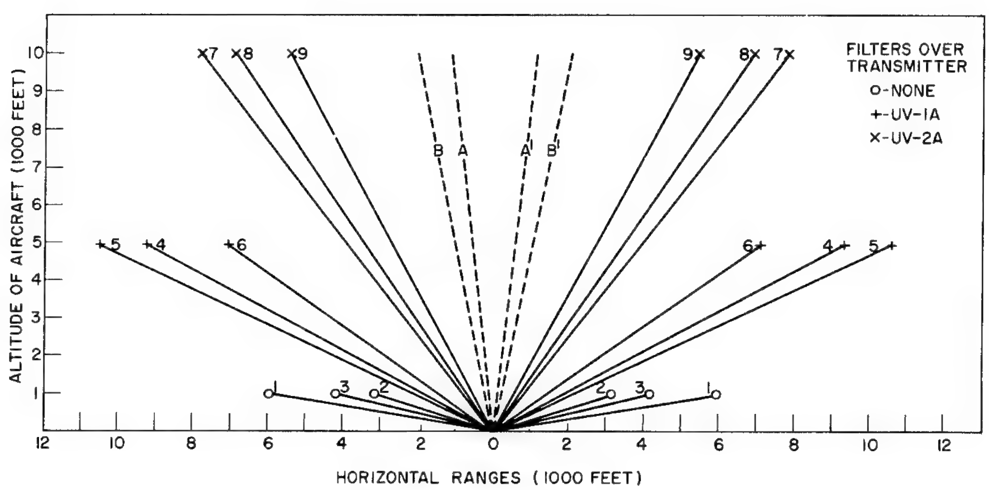

Fig. 7 - Detectable horizontal ranges across the light pulse beam from Transmitter TS-1A

TABLE 1
Detectable Horizontal Range Data

Aircraft Altitude (feet)	Transmitter Filter	Horizontal Range (feet)
1,000	None	8,900
5,000	UV-1A	18,000
10,000	UV-2A	13,400

VISUAL DETECTION OF THE LIGHT PULSE

Besides the horizontal ranges over which the light pulse can be detected by the receiver, another point of interest is its visibility with the eye. This is the reason for inserting the two ultraviolet filters over the transmitter. As can be seen from curve 1, Fig. 8, the light radiated from the transmitter contains some visible light along with the ultraviolet. However, the most light energy is radiated at wavelengths below 500 millimicrons, in the region where the sensitivity of the eye is decreasing as shown by curve 3 (Ref. 7). Even so, the light from the transmitter is easily visible at distances of over two miles when the observer is within the light pulse beam. Therefore, if it is necessary for visual security to signal with ultraviolet light, to which the eye is very insensitive, a filter such as UV-1A must be inserted over the transmitter. When this is done, the relative amount of radiant energy emitted from the transmitter is shown by curve 2 in Fig. 8. However, a large amount of useful radiation is sacrificed by using the filter.

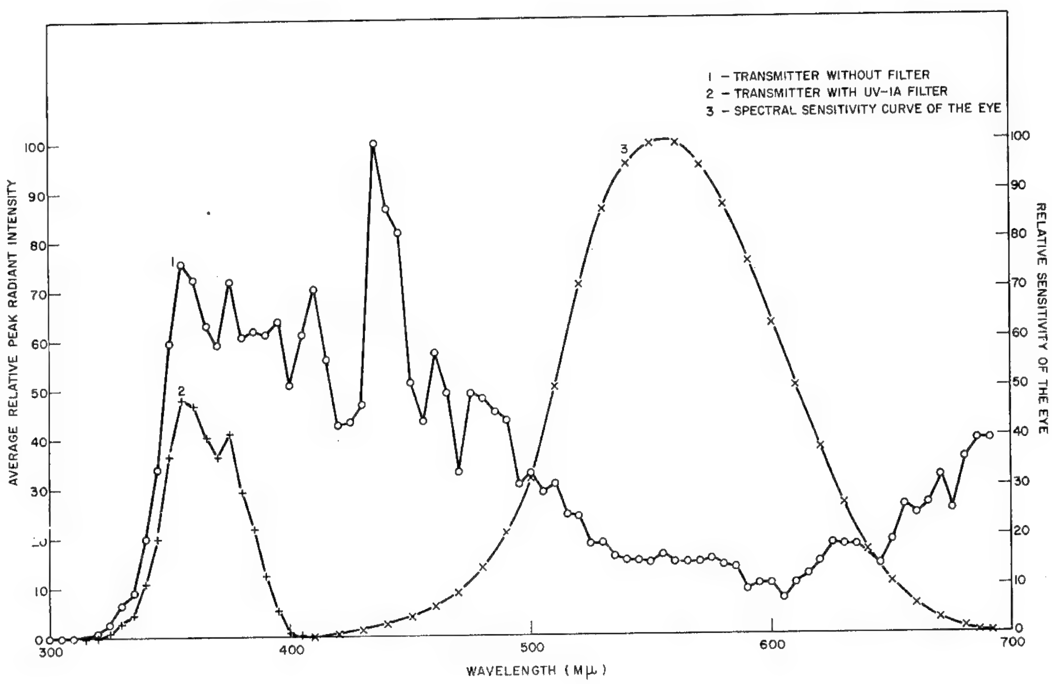

Fig. 8 - Average relative spectral peak radiant intensity of the light pulse beam from Transmitter TS-1A and the spectral sensitivity curve of the eye

The visibility of the light pulse emitted from the transmitter depends upon many parameters such as the transmission of the atmosphere, the distance between the observer and the transmitter, the background illumination, and the angle from which the observer is viewing the light pulse. However, to give some idea of the visibility of the light pulse at night when the eye is not dark adapted, the approximate maximum angles inside of which the light pulse could be seen at two different distances between the transmitter and the observer have been recorded. The observer was stationed on a building roof at the Naval Research Laboratory where the background illumination was created by the many bright lights which illuminate the buildings and grounds throughout the Laboratory. Therefore, it was impossible for the eye to become dark adapted. When the transmitter was 1040 feet away the light pulse could be seen within a maximum angle of rotation of the transmitter of about 150 degrees; at 8580 feet the angle narrowed to about 60 degrees. When these angles are compared with those of the light pulse beam of between 13 and 23 degrees as shown by Fig. 5a and 5b, it can be seen that even at distances approaching two miles the observer need not be within the light pulse beam, where the intensities are the greatest, to detect the radiation visually. Under the very same conditions the light from the transmitter could not be seen when it was capped by the UV-1A filter.

During the flights described earlier, the pilot and lookouts saw the light pulse for short periods of time while flying over the transmitter. However, they had not been trained to recognize the particular signal and several other factors interfered. Due to the pilot's position in a P2V-7 aircraft, his field of view was severely limited especially for those objects over which the aircraft was passing directly. Also, there was a scattering of other lights on the ground in the vicinity of the transmitter which made it difficult to recognize. Furthermore, the night was clear and a full moon shone thus bringing the background illumination to a high level.

EQUIPMENT EVALUATION

The transmitter has operated very satisfactorily. A total of over 55,000 light pulses were emitted by the LSD-2 flashtube. At the rate of three flashes per second the above number of flashes account for an operating time of about five hours of continuous flashing. The main objection to using the LSD-2 flashtube is its lowered breakdown voltage over the period mentioned. When it was new, the breakdown voltage was measured to be 14 kv. After approximately 55,000 flashes, the breakdown voltage had decreased to about 7 kv. Another undesirable feature of the LSD-2 is that the discharge column follows a crooked path along the glass envelope at times thus causing discoloration on the envelope.

The other components of the transmitter equipment also have performed well. The energy storage capacitor has been found to be in excellent condition. The relay contacts have discolored somewhat, but they have not become pitted. The automatic pulser in the transmitter controls triggers the flashtube dependably. Also, the counter records each time the flashtube is triggered without fail.

The receiver operated well aboard the P2V-7 aircraft. A total dynode voltage of 725 volts was placed across the 6199 multiplier phototube. According to the published data (8), this corresponds to a current amplification of about 45,000. When the phototube is kept in total darkness in the laboratory, the total dynode voltage can be increased to 950 volts, which corresponds to a current amplification of 400,000, before spurious triggers occur. Thus, the bright moonlight resulted in sacrificing a factor of nine in the gain of the multiplier phototube. At times when the plane banked for turns, the photocathode was illuminated directly by moonlight and the background noise increased considerably as indicated by the number of random audible notes heard on the earphones.

The aircraft vibration of the receiver had little effect both upon the multiplier phototube and upon the pulse amplifier. The trigger and sweep stability controls were set at the same positions during flight as they were when the receiver equipment rested on a laboratory work bench.

DISCUSSION

The present equipment was found to be in very good operating condition for underwater-to-air signalling. Only two major changes have suggested themselves during this preliminary field work. First, considering the magnitude of the errors in the measurement of the ranges across the beam of the light pulse, the flashing rate may be reduced to two per second in order to extend the life of the flashtube. Secondly, more gain can be incorporated into the amplifier of the receiver since vibration due to the aircraft is not as serious as had been presumed. More gain in the amplifier is especially desirable since it amplifies selectively; that is, the bandwidth can be adjusted to amplify only those frequencies included in the light pulse. This type of amplification discriminates against noise and has a tendency to increase the signal-to-noise ratio.

Figure 9 shows the effect of a smooth water surface on the light pulse beam from Transmitter TS-1A. The transmitter is presumed to be at a depth of 150 feet. The angle formed by the lines A and A′ denote the beam in the plane in which it has a minimum angular spread as taken from Fig. 5a, while the angle formed by the lines B and B′ outline the maximum angular beam spread as taken from Fig. 5b. Refraction at the air-sea interface will cause beam AA′ to open up from an angular spread of 13 degrees to about 17 degrees; beam BB′ will open up from 23 degrees to 31 degrees. Therefore, according to Fig. 9 if one were to fly over the transmitter at 5000 feet while it was submerged to a depth of 150 feet, one would be within the light pulse beam for a horizontal distance of approximately 1600 feet in the case of beam AA′ and 2800 feet in the case of beam BB′.

The above ranges would be approximately true for extremely smooth water where scattering effects would be negligible. However, at sea the beam will be spread by scattering both within the water and at the surface where the sea state will be a determining factor of the degree of scattering. Previous work (4) conducted in rough seas indicates that the beam opens up considerably after passing through the water and into the air. In order to design a transmitter and receiver which will better fit the needs of submarine-to-aircraft signalling, it will be necessary to investigate this scattering effect at the surface of the water.

The visibility of the light pulse is something which will vary considerably under different circumstances. The background illumination, the depth of the submarine, the type of water through which the light pulse must be transmitted, the filter over the transmitter, and the intensity and duration of the light pulse are the chief factors affecting how well the signal can be seen. Other factors to be considered are the altitude of the aircraft, the sea state, and the transmission of the atmosphere. It should be pointed out that by limiting the spectral content of the light pulse to the ultraviolet for visual security, a serious handicap is placed upon the effectiveness of the equipment both because of the decreased light output and the decreased transmission of some types of seawater in the ultraviolet.

One of the most important aspects of the problem at present is the development of a light source which will more adequately fulfill the requirements imposed by submarine-to-aircraft signalling. Briefly stated, there is a need for a flashtube which has all or most of the following characteristics: (1) the emission of high intensity, short duration, reproducible light pulses with a specified spectral distribution, (2) positive and easy triggering,

(3) a negligible change in the breadkown voltage during the life of the flashtube, (4) very little erosion of the electrodes and discoloration of the envelope, (5) a rugged construction which will withstand high input energies, and (6) more efficient conversion of electrical energy to radiant energy in the desired portion of the spectrum. Progress has been made along the lines of developing such a flashtube. However, additional basic research is necessary to realize any major improvements over the flashtubes commercially available at the present time.

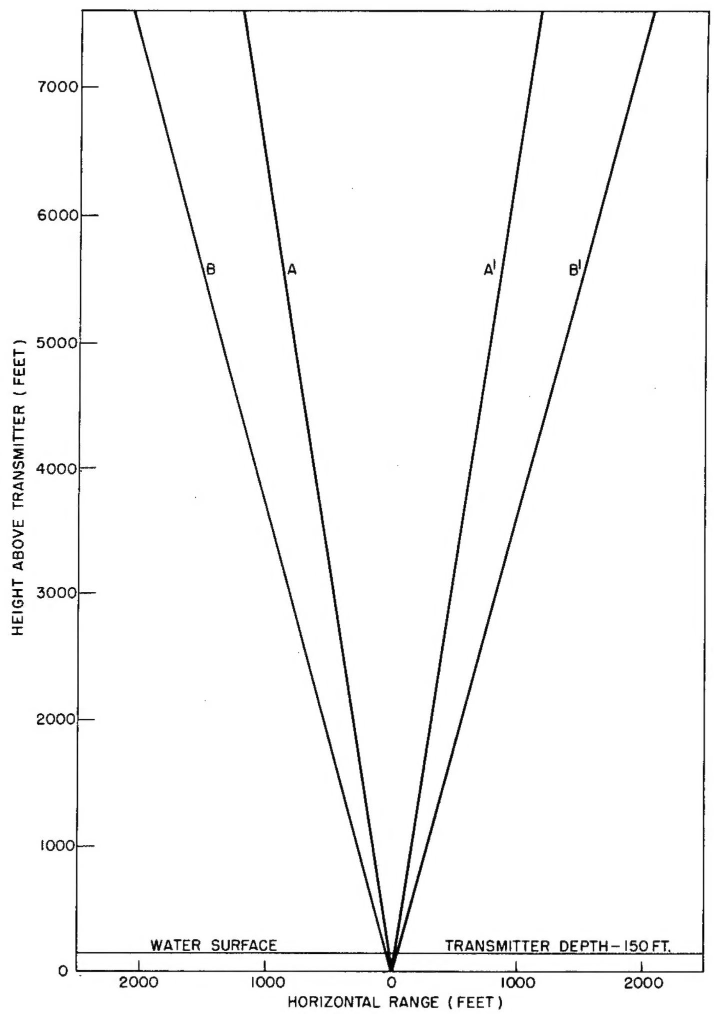

Fig. 9 - Effect of smooth water surface on the light pulse beam from Transmitter TS-1A

FUTURE PLANS

The present equipment is being readied for installation aboard a submarine and an aircraft in order to obtain experimental data on the transmission of light pulses from beneath the sea to an aircraft. Assist services have been requested for this work. In connection with this phase new means of increasing the detectable horizontal ranges are being studied.

Another phase of this problem has to do with the development of a flashtube which will more nearly meet the requirements imposed by the particular application. Some progress has been made toward the development of such a flashtube. However, a more intensive program of research is anticipated in this direction.

ACKNOWLEDGMENTS

The authors are grateful for the assistance which they received from Commander Deitchman, who arranged the flights and piloted the P2V-7 aircraft. Also, we would like to thank Mr. E. J. Williams at the Chesapeake Bay Annex of the Naval Research Laboratory who assisted in maintaining radio contact between the aircraft and the personnel at Tilghman Island. For his observations and operation of some of the equipment, special thanks are due Mr. Claude V. Acton.

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